Progress Report for NASA Grant NAGW-4777 for 1996-1997 "Improved Estimates of Clear Sky Longwave Flux and Application to the Tropical Greenhouse Effect"

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1 Project summary from the original proposal

The first objective of this investigation is to eliminate the clear-sky offset introduced by the scene-identification procedures developed for the Earth Radiation Budget Experiment (ERBE). Estimates of this systematic bias range from 10 to as high as 30 $W\,m^{-2}$. The initial version of the ScaRaB data is being processed with the original ERBE algorithm. Since the ERBE procedure for scene identification is based upon zonal flux averages, clear scenes with longwave emission well below the zonal mean value are mistakenly classified as cloudy. The erroneous classification is more frequent in regions with deep convection and enhanced mid- and upper-tropospheric humidity. We will develop scene identification parameters with zonal and/or time dependence to reduce or eliminate the bias in the clear-sky data. The modified scene identification procedure could be used for the ScaRaB-specific version of the Earth-radiation products.

The second objective is to investigate changes in the clear-sky outgoing longwave radiation (OLR) associated with decadal variations in the tropical and subtropical climate. There is considerable evidence for a shift in the climate state starting in approximately 1977. The shift is accompanied by higher SSTs in the equatorial Pacific, increased tropical convection, and higher values of atmospheric humidity. Other evidence indicates that the humidity in the tropical troposphere has been steadily increasing over the last 30 years. It is not known whether the atmospheric greenhouse effect has increased during this period in response to these changes in SST and precipitable water. We will investigate the decadal-scale fluctuations in the greenhouse effect using Nimbus-7, ERBE, and ScaRaB measurements spanning 1979 to the present. The data from the different satellites will be intercalibrated by comparison with model calculations based upon ship radiosonde observations. The fluxes calculated from the radiation model will also be used for validation of the ScaRaB fluxes.

2 Progress during 1996 to 1997

2.1 Original implementation plan for first two years

As originally proposed, in the first year the investigation would focus on the tasks related to the improved identification of clear-sky data:

1. The Nimbus-7 SRR data set will be processed to derive new MLE and limb-darkening parameters following the methods of [*Suttles*, 1989]; and

2. The new parameters will be tested on unfiltered ERBE clear-sky radiances, and compare the resulting fluxes with calculations based upon ship radiosonde measurements of temperature and humidity.

In the second year, the investigation will begin to address combining the Earth-radiation data from multiple satellites to estimate greenhouse effect:

1. The Nimbus-7 and available SCARAB monthly mean data will be analyzed to derive the greenhouse effect (this has already been done for ERBE);

2. The tropical ship soundings will be acquired, and coincident pairs of satellite clear-sky and ship radiosonde measurements will be identified for the intercalibration process;

3. The fluxes from the coincident soundings will be calculated, the offsets from the satellite measurements determined, and the differences in the offsets between Nimbus-7, ERBE, and SCARAB will be characterized as functions of SST, atmospheric humidity, and lapse rate; and

4. The analysis of the new MLE parameters will continue using the SCARAB unfiltered radiance data.

2.2 Research completed

During the first year of the project, progress on the objectives related to improved scene identification was hampered by difficulties in reading the Nimbus-7 data used to construct the original ERBE scene-identification and limb-darkening models. In the second year, the Nimbus-7 data was successfully decoded and analyzed.

One of the first-year objectives was to investigate the large differences between ERBE clear-sky OLR and OLR calculated from coincident ship radiosonde profiles under conditions of low relative humidity [*Collins and Inamdar,* 1995]. Since ScaRaB is using the same techniques for obtaining clear-sky fluxes, it is expected that the same systematic biases should affect the ScaRaB products. These differences have equal magnitude but opposite sign compared to the systematic OLR differences observed at large relative humidity [*Hartmann and Doelling,* 1991; *Ockert-Bell and Hartmann,* 1992]. The latter differences are understood to result from the ERBE scene-identification model, which is biased toward the properties of clear-sky scenes in subsidence regions. However, the differences between the calculated and measured OLR under low relative humidity is not yet understood. In a process of elimination, *Collins and Inamdar* [1995] proposed that there might be biases introduced through the limb-darkening models. The physical mechanism is that limb-darkening should be greater for wetter atmospheres than drier atmospheres. The ERBE limb-darkening models average over both these conditions, thus conceivably leading to an overestimation of clear-sky fluxes in dry atmospheres from large slant-angle observations.

The relation of the limb-darkening effect to convective activity is shown in Fig. 1. The figure shows the clear-sky radiances as a function of satellite viewing angle binned by season as in the original ERBE scheme and by OLR on the same day of the clear-sky observation. Since measurements and analyses of upper tropospheric humidity are very uncertain [*Gutzler,* 1993], the all-sky OLR has been used as index of convective activity and associated moistening of the upper troposphere [*Fu and Soden,* 1995]. Within the scatter in the measurements for each satellite viewing zenith angle bin, it has not been possible to find statistically significant differences between different levels of convective activity as indexed by OLR. These results do not support the hypothesis that there are appreciable differences in the limb-darkening for convective and non-convective regions that are not captured in the ERBE limb-darkening models. Thus the cause of the differences between ERBE and model clear-sky fluxes under conditions of low humidity remains an open question. The derivation of new MLE scene identification parameters will be undertaken next.

During the second year, the comparison of ScaRaB clear-sky OLR with calculations based upon ship radiosondes has continued. Eight months of ScaRaB data have been

analyzed using techniques developed during the first year of the project. This component of the project has two goals:

- confirm whether the estimates of clear-sky OLR from ScaRaB are comparable to model calculations; and
- intercalibrate the ScaRaB and ERBE scanning radiometers using the model as a common standard.

Figure 2 shows the geographic distribution of the radiosondes for the eight months during 1994 and 1995. Of the 1680 sondes available from the NCEP archives for this period, 544 correspond to clear-sky scenes observed within a 12 hour window by the ScaRaB satellite. To confirm that the ScaRaB clear-sky scene identification is reasonable, the investigator has compared the mid-infrared brightness temperatures (IRBTs) from ScaRaB clear-sky pixels to the brightness temperatures calculated from the soundings. As shown in Fig. 3, the RMS differences between ScaRaB and model-derived IRBTs are less than 1.5 K, indicating that the ScaRaB scene-identification scheme is correctly discriminating between tropical clear and cloudy scenes.

The estimates of OLR from ScaRaB and from the model are compared in Figure 4. The root-mean-square (RMS) differences between the estimates have been computed for observations matched within 12-hour and 1-hour windows. The RMS differences are 7.4 W m^{-2} and 7.7 W m^{-2}, respectively, which are virtually identical to the RMS differences computed from a comparison of ERBE data with the same model [*Inamdar and Ramanathan*, 1994]. These results show that in terms of the agreement with the OLR calculated from collocated radiosondes, the performance of ScaRaB and ERBE is comparable.

Using the large number of collocated ScaRaB and radiosonde observations available in the second year (Fig. 2), the PI has checked to see whether ScaRaB manifests the same biases relative to calculated clear-sky OLR as ERBE. The results are shown in Fig. 5. Just as for ERBE, the calculated OLR exceeds the satellite-measured clear-sky OLR under conditions of low humidity. The sign of the offset changes at approximately 60% column-mean relative humidity, as was observed in *Collins and Inamdar* [1995] for ERBE.

2.3 Plan for Year 3

In Year 3, the investigator will complete work on the feasibility of obtaining improved clear-sky parameters from Nimbus-7 measurements to use in the analysis of ERBE and ScaRaB. As discussed in section 2.2, work on testing the sensitivity of the clear-sky limb-darkening functions to convective activity is complete. Using similar techniques, the variation of clear-sky scene-id parameters with local convective activity, which would be expected on physical grounds, will be examined. If the variation is significant, the effects of these new parameters on the regional, time-average clear-sky OLR will be tested using unfiltered ERBE and ScaRaB radiance data. This research is directed toward correcting the known biases in the ERBE data in areas of deep tropical convection [*Hartmann and Doelling*, 1991; *Kiehl and Briegleb*, 1992].

The investigator will also begin the intercalibration of the clear-sky OLR from the Nimbus 7, ERBE, and ScaRaB instruments using model calculations as a common calibration

reference. This was originally planned for year 2 of the investigation, but the plan to intercalibrate the satellites against global reanalyses was not possible because the NCEP and ECMWF analyses spanning 1979-1995 were not yet available. Although ECMWF's analysis product currently spans just the periods observed by ERBE and ScaRaB, the NCEP analysis is now available for the time period covered by all 3 satellites. In addition, the investigator plans to intercalibrate the satellites by comparing the measured OLR with calculations using radiosondes. This was also planned for year 2, but it has proven difficult to read the archive of radiosondes for the Nimbus time period. The investigator will work directly with archive specialists to insure that the radiosondes coincident with Nimbus-7 data can be used for the satellite intercomparison. As planned for year 2, the differences between the analyzed OLR fields and the satellite observations will be characterized as functions of SST, atmospheric humidity, and lapse rate. The results of this investigation will help to determine the relative calibration of the OLR measured by the three satellites for clear-sky tropical ocean scenes. This information will be used in the third year to assess long-term variations in the water-vapor greenhouse effect.

References

Collins, W. D., and A. K. Inamdar, Validation of clear-sky fluxes for tropical oceans from the Earth Radiation Budget Experiment, *J. Climate*, *8*, 569-578, 1995.

Fu, R., and B. J. Soden, A satellite analysis of deep convection, upper-tropospheric humidity, and the greenhouse effect, *J. Climate*, *8*, 2333–2351, 1995.

Gutzler, D. S., Uncertainties in climatological tropical humidity profiles: Some implications for estimating the greenhouse effect, *J. Climate*, *6*, 978–982, 1993.

Hartmann, D. L., and D. Doelling, On the net radiative effectiveness of clouds, *J. Geophys. Res.*, *96*, 869–891, 1991.

Inamdar, A. K., and V. Ramanathan, Physics of greenhouse effect and convection in warm oceans, *J. Climate*, *7*, 715–731, 1994.

Kiehl, J. T., and B. P. Briegleb, Comparison of the observed and calculated clear sky greenhouse effect: Implications for climate studies, *J. Geophys. Res.*, *97*, 10037–10049, 1992.

Ockert-Bell, M. E., and D. L. Hartmann, The effect of cloud type on Earth's energy balance: Results for selected regions, *J. Climate*, *5*, 1157–1171, 1992.

Suttles, J. T., Angular radiation models for Earth-atmosphere system. Volume II: Longwave radiation, Technical report, NASA, Ref. Publ. 1184, v. 2., 1989.

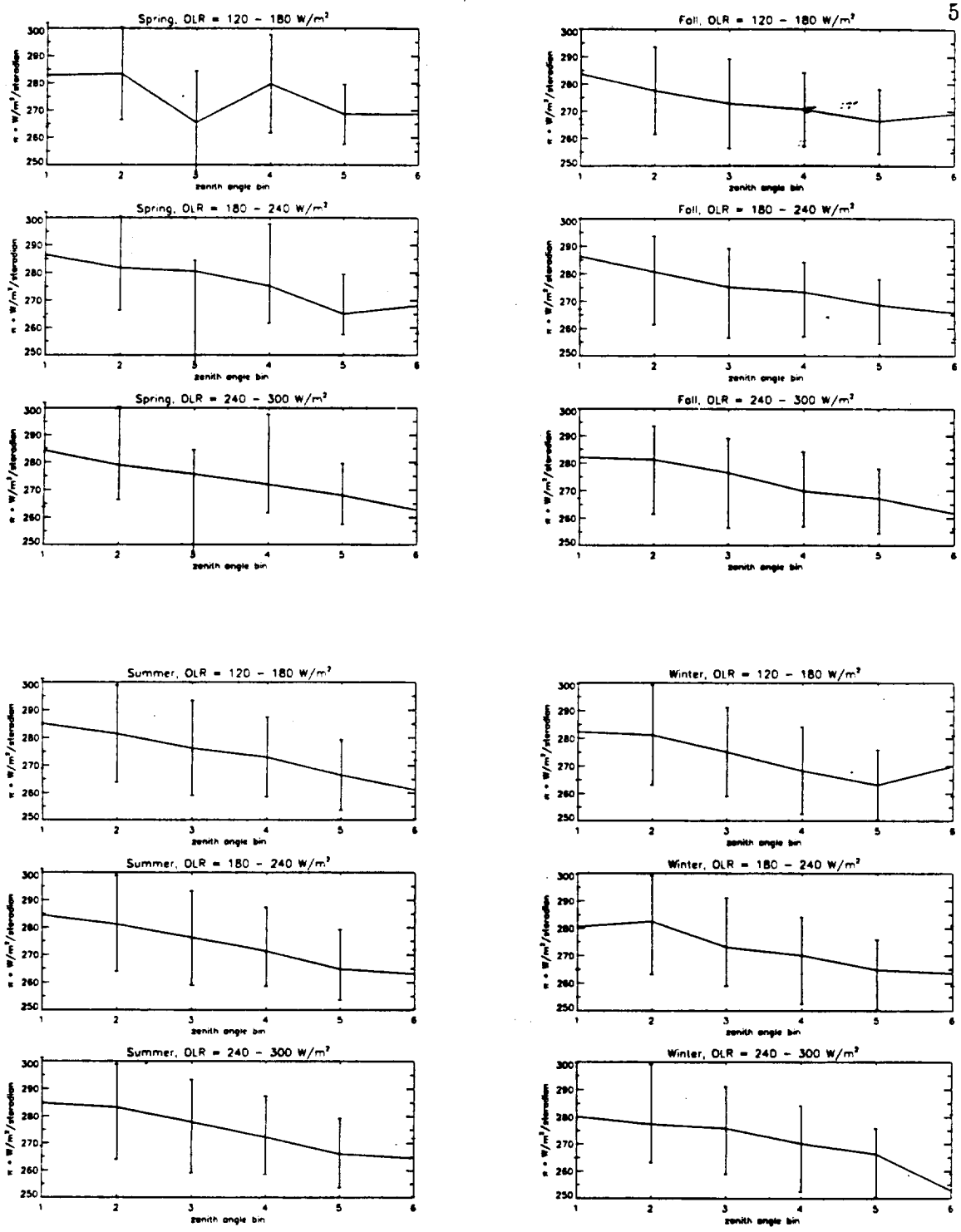

Figure 1: Limb-darkening models for clear-sky Nimbus-7 radiance data as functions of the satellite viewing angle. Observations are grouped by daily-mean all-sky OLR at the site of the clear-sky measurements and by season of the year.

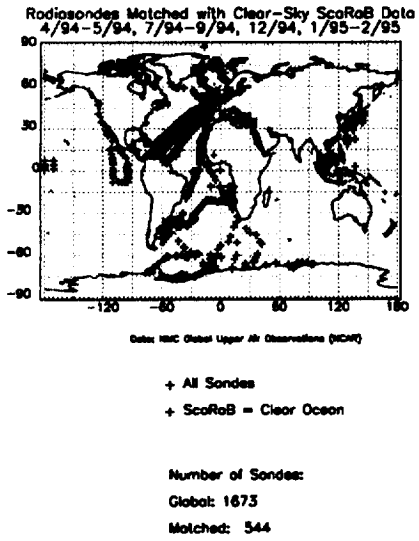

Figure 2: Distribution of ship radiosondes matched with ScaRaB clear-sky scenes during 1994-95

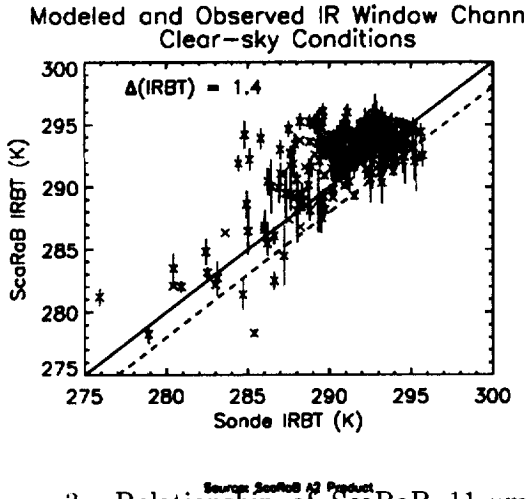

Figure 3: Relationship of ScaRaB 11-μm brightness temperatures for clear-sky scenes with temperatures calculated from matched ship radiosondes

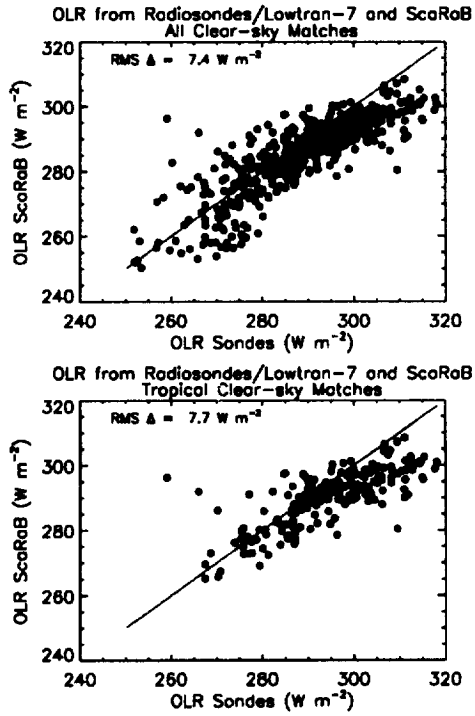

Figure 4: Relation of OLR from ScaRaB and radiosondes for 1994-95

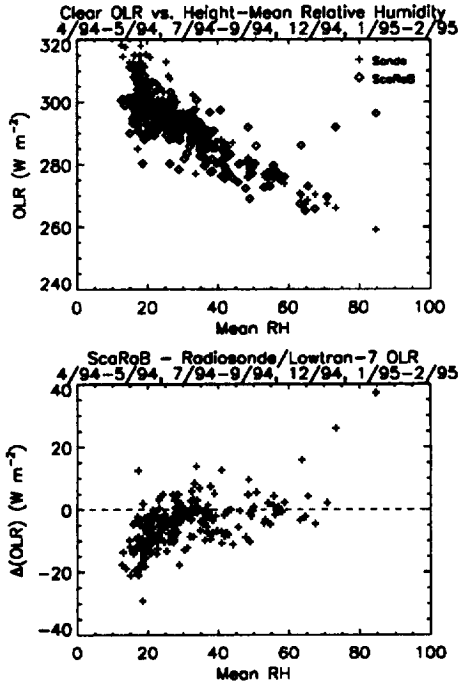

Figure 5: Variation of OLR with column-mean relative humidity